BROACHING BY HYDRAULIC MACHINE ON HIGH SPEED STEEL BROACHES.

Paper presented to the Institution, Sheffield Section, by J. G. Young, Member of Council.

OWING to the widespread interest in broaching as a machining operation, perhaps better termed a primary production process, for the engineering trades, and an ever increasing demand for speed and closer limits of accuracy, I have pleasure in presenting this paper, and hope you will all endeavour to make the discussion as interesting as possible, as I am sure there are greater possibilities for understanding the advances in production science if we take a little more trouble to investigate the changes and constant refinement in processes, without which the engineering trades could not survive.

We hear of many opinions on the evils of the speed of ultra-modern machines. There can be no evil in progress. I am not going to deal with the economic side of the displacement of labour by improved methods, but, taking the widest possible view point on the subject, I am of the opinion that there should always be some margin to refine products and methods to meet competition without increased cost to consumers if efficient manufacture is undertaken, thus creating increased demand.

The paper to-night deals with the broaching of many component parts of various engineering products. The times for production, and stock removed, given on some of the slides. are based absolutely on demonstrated performances.

The Field for Broaching.

Broaching serves an important field in the science of production engineering. It has manifold advantages in reducing cost, in the quality of finish, considering the stock removed and the irregular surface machined. In many cases there are alternative methods in to-day's intensive productive requirements.

External broaching has developed so rapidly in recent years in U.S.A. and Germany as to become an important competitor of the milling machine, and by constant refinement will challenge other machining processes which appear to be so firmly entrenched in the production of engineering commodities.

I will only touch briefly on external broaching. Crank shaft webs, connecting rods and caps, cylinder blocks, crank-shafts, universal joints, clutch levers, gear sectors, change speed levers, and steering

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columns, are a few out of many components which provide economies in production cost by external broaching.

Broaching Not a New Operation.

Broaching, as an operation, is not new, but has developed from what was termed " drifting " in the old days to a machine process and has been refined by exchanges of opinions between designers of machines and designers of tools and parts with actual users of products.

High class precision broaching by machining was until 1900 confined to the armament trade. In this country the extractor ways in rifle production were broached by machines about 1856. Anyone familiar with the extractor way, on the old Martini and other rifles of that period, will realise the importance of accuracy and repetition.

At first broaching was mostly confined to cutting keyways, and after producing rapid methods for such purpose the art developed into general machining and finishing of irregular bores such as hexagon, square, splines, etc., until the Great War of 1914 forced the production engineers to use broaching for many purposes previously deemed impossible.

The hydraulic broaching machine, except in a few instances where engineers developed the accumulator hydraulic machine for the production of parts peculiar to their company's requirements, did not become a competitive field of service until well after the war ended, but about 1922 a few hydraulic machines began to find a place in automotive production plants in U.S.A., and by 1926 the old screw type machines were practically discarded in the mass production plants of America.

Broach Design.

Broach design needs very careful planning and practice. Until a few years ago high speed steel broaches were not popular, but as the designer took more notice of chip clearances, materials being broached, stock to remove, lubricants essential to best results, so the demand for high speed steel broaches increased, and to-day many broaches are built in sections, making for closer accuracy and economy to the purchaser and user for replacement parts.

There are no standard rules for broach design ; each new application nust be reviewed to suit the results desired. Wherever possible broaches should be ground all over. The slightest tool marks, even as shallow as half of one thousandth of an inch, are in themselves sufficient to hold chips when cutting, and clog the teeth with the possibility of scored surfaces on the work.

Coolant.

The cutting coolant depends entirely on the class of material

being broached. The action of the cut by broaching is of a shearing nature and therefore generates considerable local heat, thus demanding suitable lubrication, especially when broaching steels. It is therefore essential that care and consideration be given to this for maintaining minimum productive costs, and more especially to obtain the desired finish of surfaces. In deciding the correct lubricant for general application on production of steel parts, properties for refrigerant lubricating, free flowing and cleanliness should be given every attention.

Ordinary cutting compounds such as soluble oils are fairly useful for soft steel parts, but where close finish in accuracy of surfaces is required on spongy steels and springy parts a good mineral oil is recommended. In cutting tempered and high tensile steels an inclusion of lard oil is strongly recommended. Broaching cast iron may be successfully performed by cutting dry, but a lubrication of parafin, with a small inclusion of turps, or even petrol, will preserve the broach life and produce better finishes.

Types of Machines.

The length of broaches will vary from a few inches to several feet, and only experience will show if other materials provide any advantages over high speed steel; I refer to developments in tungsten carbides which have to be considered if we are to keep pace with production science and requirements. The practicability of using tipped and inserts of cemented carbides has already been satisfactorily proved on a few isolated broaching applications, and as the demand increases so will speeds correspondingly increase.

A good example of a built up broach is one which is in use for broaching connecting rods, finishing the large bore and two faces across the end of the rod. The centre section of the broach is semi-circular in form, whilst the other two sections are flat. The three sections are the same length so that when the finishing insert is worn undersize the first section, or roughing section, is removed and the other inserts moved forward one section while a new finishing section is inserted and the whole assembly re-ground.

Shell type broaches for round bores are often designed so as to be interlocking,—that is, a male projection at one end and female at the other of each insert.

The designs of machines run in many directions. At the present time there are the old type screw pull broaches, horizontal, vertical and continuous, and also rack and pinion type, both pull and push and in some instances power presses are used. Some very excellent welding work has been executed in the fabrication of the machines.

Pumps in Hydraulic Machines

The pumps used in hydraulic machines are of the multi-piston

type, and in some applications constant delivery pumps are used, but a variable delivery is the most sought after. Constant delivery pumps are set for a specified volumetric capacity, so cannot be changed. In variable delivery type pumps, the volume and direction of flow can be varied instantaneously. Relief valves are set to open when the maximum pressure for which the pump is designed is reached. These relief valves are usually placed so as to discharge into the pump case. It is not good practice to set relief valves to operate at regular intervals, but for the sole purpose of relieving pressure when it reaches a point higher than that for which the pump was designed to operate at.

Quite a number of variable delivery pumps are designed to take care of leakage inside the pump case without auxiliary assistance. There are, however, some good variable delivery pumps that have to be fitted with an auxiliary for the leakage to be pumped back to the oil feed reservoir.

Control mechanisms for stroke or pressure adjustments vary considerably. This is one of the difficulties with hydraulic drives to machine tools, and great care should be taken to select the control best suited to the machine. Automatic pressure controls are now in service, and are in many instances a distinct advantage, for quite a number of pumps will respond instantaneously to the sensitiveness of the controls.

Pressure gauges fitted to the operating cylinders are an advantage to the operators, as the rise or fall in pressure will prove that the broach needs regrinding or that the materials are of a different tensile, and so on. The operator can immediately notify his section supervisor so that the cause of the variance in pressure can be immediately investigated.

Pump pressures up to 1,500 lbs. per square inch are quite common in hydraulic broaching machines, and a good mineral oil of viscosity from 150/220 seconds saybolt at 100°F., is recommended for the pressure cylinders. The oil should be well filtered and free from grit. Work holding fixtures play an important part in broaching, rigidity and accuracy in alignment being most essential.

Uses.

Broaching is used for a large variety of parts, made from various materials. Amongst these are leather, fibre, steels of all description, aluminium, bronze, copper, yellow metals, white metals, cast iron, and so on.

It is not essential to machine faces or bores before broaching. On many applications a good deal depends on the work being performed. In the production of cylinder blocks the castings are rough—just foundry snagged—and in the production of bushings, broaching again begins from the cored hole, in many plants engaged on manufacture of bushings. I mention these instances to avoid

confusion with splined holes and cylinder bores which may be in the minds of some of the members of this audience.

Some very rapid production methods are complicated in setting up, but broaching is very simple and handling time is reduced to a minimum. One of the easiest applications producing the most accurate results is broaching rifle nuts for pneumatic tools, the splines of which are spiral, where the broach revolves the work on a ball race during the action of cutting.

List of Slides used during Lecture.

(1) Illustrated a special broach support for heavy work, is very rigid, and a great time saver, avoiding any question of fatigue for the operator. Ball bearings are fitted. For broaching repetition work, calling for the use of heavy broaches, this special fixture is highly recommended.

(2) Vertical, hydraulic machine, built up of steel plates welded together, the only casting in the machine fabrication being the main oil cylinder. Machines of this description are regularly being constructed for capacity from three to 50 tons. The ways of the machine are steel, hardened, and ground. Bronze shoes are fitted to the travelling carriage, and these inserts are easily adjusted and replaced. The pump and motor is totally enclosed on the machine. Treadle operating adjustments.

(3) A standard machine used for re-grinding and sharpening broaches. The heads on this machine are made to swivel, and ball bearings are fitted throughout.

(4) A pump assembly with motor ready to be fitted to machine pedestal (shown on the left of the picture).

(5) Small illustration of automatic pressure control.

(6) Illustrated fixture complete for broaching cylinder blocks. The fixture is bolted to horizontal hydraulic broaching machine. The bearings on the cylinder case are broached in line, $^1/_{32}$ in. stock is removed from rough machined faces, and the limits maintained on production are half of one thousandth of an inch. Production, 70 complete blocks per hour. All broaches used for this operation are H.S.S. with an average life of 4,500 blocks per grind, and an average of 50 grinds per tool.

(7) Typical production by hydraulic broaches. There are four broaches of H.S.S. in use, each independent, but all pull together over the work faces.

(8) Some broached connecting rods.

(9) Broach designed to remove stock from irregular shape bores to produce a perfectly round finish bore.

(10) Duplex broaching fixture.

(11) Double headed vertical hydraulic machine with welded frame, pedal controls, etc.

(12) Built up broach showing simplicity in design for replacement of sections. When replacing parts on this broach the first section is removed, the other sections brought forward, new section fitted, and the whole assembly reground as one unit.

(13) A group of 16 different components externally broached.

(14) Illustrated the flat sided broach designed to remove a considerable amount of stock from the surfaces.

(15) A continuous broaching machine. Adaptors for easy loading and unloading worked faces.

(16) External broaching operation of segments. One broach slips free from locking drive to avoid damage when re-loading, and each broach is guided to assure accuracy. The broaches in use are over 5 ft. long and $1\frac{1}{4}$ in. wide $\times$ $^{13}/_{16}$ in. deep.

(17) A strongly constructed vertical hydraulic broaching machine of welded construction showing a quick acting fixture in position.

(18) Hydraulic horizontal heavy duty machine in operation showing free flowing cutting coolant with broach support, etc.

(19) Illustrated the broaches at work on No. 18.

(20) Very large diameter support for broaches of hydraulic machine. The bore being 11 in. in diameter, stock removed approximately $^{5}/_{16}$ in.

(21) A close-up view of the 11 in. dia. broach and support, etc.

(22) Vertical multi-cylinder hydraulic broaching machine, broaching arrangements for spanner jaws with quick acting fixtures and new style broaches.

Discussion.

MR. G. GILFILLAN (Section President) : Mr. Young has given us an interesting paper to-night on a subject that I, personally, am pleased to see is so far to the fore. I am really surprised to find that broaching has advanced so rapidly. While I am surprised, I am gratified to learn that some firms are live enough to install these machines. With regard to the slide of the marine connecting rods, two thoughts passed through my mind. One was the economical cost of manufacture. There are various ways of manufacturing these connecting rods. I wondered whether it was not cheaper to put them in a batch of 30 per machine, and grind the faces, or to put them on a locating table and mill the faces with continuous loading. With these methods, the cost of tools is very small, but with broaches it may be rather a stiff figure. We had a certain job to do, where the pinion was about 11 in. long, 1.6 in. bore, 12 splines, and the splines were ¼ in. deep. We wrote off to a very prominent manufacturer of broaches in this country, who replied that we should want 12 broaches to do that particular job. At the same time we sent an enquiry out to another company which was controlled by an American firm ; they replied that we should want three broaches. We ordered three broaches, and found that the job was done with these three very satisfactorily, and accurate to any standard tolerances specified. That was a case where you might be charged for some broaches that were not required. On the subject of pumps. It does not matter how good you make the pump, what you have to look after is the oil. Oil in any good pump is the life-blood of that plant, and you cannot take too much care to see that the oil is pure. The question of coolants Mr. Young dealt with. This is another important factor to get the best results from your broach, also chip clearances. I do not know whether Mr. Young has had any experience of tubes, 4 ft. long, 2¼ in. diameter bore. It is not an impossible task, but it is a question of the economical cost that I am after.

MR. YOUNG : In the first case you mention milling connecting rods and the cost of setting up for broaching the faces. Setting broaching equipment is one of the least costly of any primary production operations I know of, and in respect to costs is approximately one-sixth that of milling. In estimating for increased trade, we must follow the market trend, and ascertain the best means of reducing costs ; broaching flat faces is definitely an operation to be considered, and is challenging the milling machine. The broaching of flat surfaces such as faces of gear wheels was

introduced in U.S.A. about ten years ago, and in my opinion was the commencement of external broaching.

Broaching long tubes is fairly common practice, and tubes 4 ft. long × 2½ in. diameter bores are not looked upon as long tubes in the broaching sense, a lot however, depends on class of materials, stock to remove, type of machine and finish desired. Copper and brass tubing have been broached for many years. Some excellent close precision results are obtained by broaching copper, such as compensators for pumps, and in respect to lubricant for copper, stale beer was at one time permitted and gave excellent results, but to-day clear water is more generally used.

Respecting the oil for the pressure pumps for variable speed applications to hydraulic broaching machines a good grade mineral oil of viscosity from 150 to 215 seconds saybolt at 100° to 110°F., is recommended; the oil should be well filtered to prevent grit inclusions.

MR. HOLMES: I would like to ask Mr. Young, apart from the cost of the tools, what is the limit for the width of face that can be externally broached? I have seen some instances of jobs that have been broached, that the man in the street would not believe had been broached and not drilled and reamed. Why cannot we do blooms by broaching, and what are the reasons against it?

MR. YOUNG: The chief reason against broaching blooms is, I assume, that it has not yet been introduced; it will come. In respect to width of faces externally broached, the biggest job I have seen and had experience with, was 14 in. × 7 in., mild steel, and nearly ten thousand faces were broached with one regrind of the broach. I have seen girders as long as this room broached across the faces (machining radii), and handled by pneumatic clamps just as easily as any light work is handled. The broaches for such work are built-up sections.

MR. SIMMONS: I believe the original method of broaching square taper holes was to broach one face at a time. Has there been any further advance, or must each corner still be individually treated?

MR. YOUNG: This is a very accurate precision job, and being tapered it is not possible to machine by broaching more than one corner at a time.

MR. HARRISON: You made a remark a short time ago in reply to Mr. Gilfillan about the cost of broaching compared to milling cutters. You stated it would be one-sixth of the cost. With milling cutters after using they can be ground; with a broach, do the circumstances alter? Once a broach is ground isn't it below size? I fail to see how a broach is cheaper seeing it would be undersize after grinding.

MR. YOUNG: I do not think that point arises. Mr. Gilfillan mentioned broaching the faces of connecting rods. Built up broaches

would be used, and if made correctly 6,000 pieces per grind should be easily possible. What I did refer to was the question of capital investment. If machining connecting rods was a new product to a company, or the quantities to produce called for consideration of additional plant, then broaching equipment can be installed at one-sixth the cost of milling equipment ; in fact it is actually being proved to-day in industry in U.S.A. and other countries overseas.

Mr. Fidler : In the slide showing the twelve splines internally broached, I was rather surprised to find one broach would remove the stock and be sufficient. The fact determining the pitch of teeth is usually the length of the hole to be broached. The broach illustrated did not seem to me long enough to do the job in one pull through for the length of bore.

Mr. Young : I am inclined to agree with you, and it is possibly an error on my part. If the work piece is 9in. long and depth of spline 3/16in., two broaches are preferable, for on such diameters it is not good practice to make the pitch of teeth more than 1½in., and the ideal broaching results are obtained when a broach is cutting freely and balanced by one tooth entering the work as another tooth is leaving.

Mr. Fidler : There was another point ; the effect of the lubricant and breaking away of materials as the broach leaves the work piece. I suppose that when the broach is properly made and the teeth kept sharp, that there is no fear of this. The other point I should like information about is flat broaching. I take it the example shown of broaching spanners was not a surface broach.

Mr. Young : I would not say the breaking away of materials is entirely eliminated, for on such as fibre and ebonite allowance is made for this, but a lot depends on keen cutting and lubrication when broaching metals. It is impossible to recommend standard lubricants ; a good soluble oil is generally used, but very often it is necessary to add body to the lubricant, which will vary in cutting spongy springy materials, or high tensile, sometimes lard oil added is very useful, in others turpentine is necessary and so on.

With respect to built up broaches, the first serious attempt of this kind for production of repetition quantities was for lock barrels. Many years ago sixteen hundred per hour per machine was the output, and in more recent years by installing hydraulic machines the production has been trebled, and if we realise the barrels are 9/16in. diameter, about 1¼in. long with a figured slot ¼in. deep, brass castings, this is an excellent production method. If broaches built up in sections are properly designed and manufactured, the replacement or adjustment of sections that have worn undersize is a simple process.

Mr. Lievesley : In the instance of broaching straight from

cored bores, is any trouble experienced with the sand, especially on the first two or three teeth ?

MR. YOUNG : Sometimes, but a lot depends on how the castings are handled. In the case in mind, the bushings are machine cast ; the next operation is breaking off the runner, then the bushings are ready for broaching, which is performed vertically at fifteen feet per minute. The first operation is to push an elliptical dummy through the bore—this has the effect of stretching the metal—then the broaching follows. The lead on the broach is oval, as it must be, seeing the bushings are cast, and stock removed by each of the first three teeth of the broach, say for 1¾in. finish bore size, will be at least 1/32in. (over thirty-thousandth of an inch) gradually tapering off until the last three teeth are parallel for finish size, the length over cutting teeth for a bushing 3in. long would not exceed 7in. the overall length of broach being about one foot, stock removed from ⅛in. to 3/16in.

I have never seen high speed steel broaches used for this class of work ; the tools usually are produced from a low nickel case hardening steel, one reason being that due to the nature of the work two to three broaches may get broken in succession, but taken over average run the broach life exceeds 50,000 pieces and it is doubtful whether high speed steel would lower tool costs per piece in this instance. Broaching from cored holes in cast iron is fairly common practice.

MR. MARRIOTT : I am extremely interested in the example shown of broaching blind holes in transmission gears. I assume the piece I am looking at is a top gear. I wonder how much the broach is taking out.

MR. YOUNG : That particular sample is out of a Vauxhall transmission. A multi-jig is used for drilling the holes, and an external broach finishes the form of tooth from the drilled hole. By the courtesy of Mr. Weatherley I have illustrations of the broach and fixture used for this operation and am pleased to hand them over for your examination.

MR. CLARE : Has the lecturer had any experience of broaching spirals such as gun rifling ?

MR. YOUNG : Boraching spirals is successfully performed in many pneumatic tool plants, especially on such items similar to rifle nuts, the material for which varies from high tensile steels to non-ferrous alloys and even fibre compounds. In some spiral broaching operations it is desirable to permit the work to freely revolve on a ball race ; the spiral on the broach usually being a lead in excess of 12in. which is sufficient to revolve the work piece during the cutting action of the broach.

The speed of the broach depends on diameter, but a number of the riflenuts will be about ¾in. in the bore, with hydraulic machines,

in steel 7ft. per minute, non-ferrous 20 to 24 ft. per minute, and for fibre 28 to 35 ft. per minute are the actual cutting speeds.

Rifling guns is another proposition, but has been successfully performed and could be rapidly developed as a production operation, but must be confined to guns with straight bores. Many guns have a slight taper and this eliminates possibilities of broaching, also the broaching would need to be confined to guns not over 6in. (six inches) bore in my opinion, although research work and necessity often proves otherwise.

MR. MARRIOTT : Some of the hefty jobs illustrated must cost a lot of money, and could the lecturer give some of the advantages of hydraulic broaching ; also is it not advisable to have only a single broach ?

MR. YOUNG : There is actually no limit to size of work that can be broached ; it is as on all production operations—a question of handling, and quantity.

I have seen large rotor wheels weighing well over twenty-five tons externally broached ; I might say these wheels did not rest on the broaching machine, but were conveyed into a pit wherein were fitted hydraulically adjustable Vees so that any error in turning (the wheels were approximately 15 feet in diameter) could be allowed for in locating the periphery of the work for broaching. The actual operation performed was cutting dovetail slots $4\frac{5}{8}$ in. $\times$ $3\frac{1}{2}$ in. and $1\frac{1}{8}$ in. to $1\frac{1}{4}$ in. deep, 12 slots per wheel—the face and length of slot would vary according to type from 12 in. to 16 in.

First operation was to pull straight broaches cutting slots 3 7/16in. wide $\times$ $1\frac{1}{8}$ in. to $1\frac{1}{4}$ in. deep, then follow with the dovetail finishing broach. The operation actually reduced machining time from six hours per slot on a planing machine to 20 minutes per slot broaching time. The work was free of the broaching machine face by at least $\frac{1}{8}$in.

The cost of broaches would obviously be more than tools for the planing machine, but the installing of broaching equipment released the planing machine for other work and the capital invested in broaching equipment was quickly written off due to time saved per piece, one machine being sufficient to cope with work previously requiring two heavy planers night and day. In addition to economy in operation costs, the floor space occupied was less than one-third, which would again show reductions of capital employed.

In respect to length of broaches and number per operation, factors beyond just the operation have to be considered, such as hardening equipment available, length of stroke of machine already installed and so on, experience of toolmakers engaged on broach production, where concerns make their own broaches, but on hefty work one broach is preferable, even if made in sections and coupled together, which is often done in long work broaching ; by coupling

broaches to master pull shank heavy work does not have to be removed until finished broached.

There are many advantages of hydraulically operated broaching machines—first sensitiveness; then feed control; variability of speed; quick return; low maintenance costs; automatic cut out when the pull of the broach is beyond capacity of the pressure available; sight pressure gauges as a guide to operators, making it possible for them to realise by increased pressure being registered the broach is dull or materials are not to standard for tensils, etc. Finally, by low pressure required to return the broaching crosshead and broach, should the tool by any mischance not be guided correctly, and make contact with either the fixture of back face of the machine, the light pressure being employed is insufficient to smash the tool, the machine automatically cuts out.

There are several types of pumps employed, mostly of multi-plunger construction, some providing for leakage inside the pump case, which ensures free lubrication of the working parts, whereas with others it is necessary to provide an auxiliary system, which usually consists of a tank under the pump to catch the leakage and a small pump to return the oil to the system.

The efficiency of hydraulic pumps is usually high, but their control for machine tool use is costly and needs development before hydraulic applications are more generally used in machine tools, but, for broaching, the hydraulic system, is the easier to control as the operation is a reciprocating straight line motion.

MR. WILLIAMS: Could you give us any idea of the amount of material to remove per tooth especially broaching wide and deep slots?

MR. YOUNG: It just depends on the shape of the slot and material to broach. In the case of the large electric rotor wheels previously described the stock removed per tooth, nine teeth cutting, was .011 in. (eleven-thousandths of an inch) for the parallel slot, two broaches 86 in. long being used, and one only for the dovetails, material being cast iron. It is quite common practice to remove .007 in. per tooth for roughing operations in steel components, but actually there are no standards, each application depending on materials to be machined and equipment available, also if speed of machine permits the use of high speed steels for broaches.

MR. GILFILLAN: The lecturer mentions high speed steels and carburised steel broaches. We all know the difficulties with carburising cutting tools. I had rather an amusing experience broaching a round bore. We had a high speed steel broach sent to us for the job; we could not keep a round bore, so made up a cast steel one which did the job quite satisfactorily. Could Mr. Young explain this?

MR. YOUNG: It is just possible the high speed steel broach was

not properly fabricated, too much or insufficient land, chip clearances not properly provided, fillet at root of teeth irregular and possibly soft spots would contribute to errors, so also might the speed of machine; any broach to give satisfaction should be ground all over. I could not offer any definite reason why the broach failed on this particular job.

Broaching long holes, such as Cluster Gears, is fairly standard practice to-day, but care needs to be exercised in preparing the bores for broaching, as it must not be expected a broach can pull a bore into straight line. A little thought in this direction will reduce costs. In respect to tipping broaches, I have seen broaches successfully tipped with high speed steel, Stellite, and tungsten carbides; the question of speeds enters into the use of tipped broaches, especially will this be so when Wimet, Widia, Ardalloy, and many other tungsten carbides are introduced into broach design; at present stellite is more generally used. Developments in this depend on the production desired, and production value per broach.

MR. SIMMONS: Is there more risk of breakages in manufacturing high speed steel broaches compared to carburised or tool steels?

MR. YOUNG: No. In producing high speed steel broaches take care in machining, see all faces and surfaces are clean, especially the radius at the bottom of the teeth, also give the broach a slight set before hardening, and carefully watch the pre-heating temperatures.

MR. HARRISON: Is there such a thing as an inserted tooth broach, one where if a tooth breaks off it can be replaced?

MR. YOUNG: Inserted teeth are not generally developed for broach manufacture, although in special instances they have been used. Any number of broaches are made in sections, which are interlocked to standard design to facilitate replacement of sections.

MR. WEATHERLEY: Further to the question of steels and speeds for broaches, we use as a constant, the carburised broach, the cast steel broach, and the high speed steel broach. We do not provide for carburised broaches to run at a greater speed than eight ft. per minute, cast steel 12 ft., and high speed steel up to 30 to 40 ft. per minute, if necessary.

MR. FIDLER: What would you suggest using for broaching $\frac{7}{8}$ in. hole hexagon or square in a 7 in. length of tube in high tensile steel?

MR. WEATHERLEY: We have just laid a job out 15 in. long, $\frac{7}{8}$ in. bore, and using eight broaches (about half the number previously used) this job finishes dead hexagon $\frac{7}{8}$ in. across the flats.

MR. YOUNG: I have some relative merits of screw pull or push machines and hydraulic machines. The average speed for screw type machine is five ft. per minute, there are, however, some light machines running at 8 to 9 ft. per minute. Broaching shock absorber

cams finished complete including radius on hydraulic machine using high speed steel broaches the production is 1,000 per hour per machine; the best ever on screw broach was 250 per hour.

MR. EVANS: I should like to ask a question on control valves for hydraulic machines, for if rapid production is being maintained the control valve may operate more than a dozen times per minute, and in my experience of hydraulic valves it is quite a job keeping them tight. What sort of control valves are used?

MR. WEATHERLEY: We have experienced no trouble at all. One hydraulic machine to my knowledge has been operating seven years at very high speeds, and no maintenance cost for repairs has so far been traceable. In the high speed pumps there are no packings to go wrong, all working parts are lapped. In so far as valves are concerned these are generally of the piston type, and if properly designed any excessive pressure would bye-pass eliminating possibility of wear.

MR. YOUNG: Whilst agreeing in the main with Mr. Weatherley, my experience with variable delivery pumps leads me to advise users to set the relief valve for the pump capacity advised by the designer. I do not advocate setting relief valves to suit each broaching job, the control adjustment is sufficient to avoid overloads, when broaching.

In the several variable delivery pumps I am acquainted with, the principle is very much the same, although each follows definite features in design. Stroke adjustments vary in all types; in some instances rack and pinion are used, in other auxiliary cylinders and plungers are fitted. The more sensitive the stroke control for speed adjustment the more effective is the hydraulic installation.

I know of hydraulic reciprocating motions on machine tools of six in. stroke, and 60 to 70 reciprocation per minute with a load of several hundredweights and pressure in excess of 1,200 lbs. per square inch; a very delicate needle valve is fitted to control valve and the bye-pass recesses in the control valves were machined to ensure the volume of oil essential for operating should freely flow.

MR. WEATHERLEY: I should just like to refer to one point raised by Mr. Young, the question of relief valves. My contention is, if satisfactory control is provided, operators can be prevented from breaking broaches. Establish the load desired to push or pull the broach through the work and set the relief valve 20 per cent. above this, then in case of a jam, the oil will bye-pass, and the time taken for the oil to bye-pass is not injurious to the pump. It is, of course, advisable to take the pressure off the relief valve as soon as possible. If this is done there is no danger of breaking the broach.

MR. YOUNG: I am pleased to learn broaching machines are

designed and have advanced sufficiently to permit relief valves operating at any set pressure. A lot depends on the design of pump being used, in my opinion.

MR. GILFILLAN: We have had an excellent discussion on a subject about which there is yet much to learn. On this occasion, seeing it is my last night as President of the Sheffield Section, I am going to take the opportunity of moving a vote of thanks to Mr. Young for the excellent paper given us to-night. We have been given a good deal to think about, and Mr. Young, with his usual good nature, will do anything to make this Section of the Institution a success. Therefore, on your behalf, I will ask Mr. Young to accept our very sincere thanks for an enjoyable and instructive evening.

MR. YOUNG: Seeing this is the last evening this session, I am delighted at the reception given the paper and at our President's remarks. So far as the Sheffield Section of the Institution is concerned, I am pleased to have been favoured with the opportunity of again addressing you, and also to see the Section gaining strength in membership. Your retiring President, Mr. Gilfillan, has put in some sterling work in his two years term of office, and it must be gratifying to him to see the gradual increase in membership in this Section. In respect to development, it is a duty of the older members to attract the right kind of responsible men to become members of the Institution.

MODERN FOUNDRY PRACTICE.

Paper presented to the Institution, Glasgow and Edinburgh Sections, by W. G. Morgan.

MODERN foundry practice may be described as the production of castings, in improved alloys, by means which supplement practical experience with a measure of scientific control, to produce definite and exact conditions in an otherwise speculative trade and which will reduce the physical exertion that has symbolised this industry in the past. This does not mean that practical experience is ignored or unnecessary—far from it, rather, that this experience of practical methods and results is supplemented by the application of the facts revealed by the technical research worker.

To co-ordinate these two sources of knowledge it is essential to exercise definite and complete control over the various processes involved. Failure to appreciate this necessity of control has caused not only failure to achieve the anticipated results, but, in some cases, a cynical attitude towards the scientific worker and all he represents. However, the successful foundries to-day are examples of the efficiency which can be attained by the above combined efforts.

As an essential part of this control, foundries use a laboratory, either as a department of the works or an outside consultant, and whether it simply carries out routine checking of raw materials, metal mixtures, sands and fuels and the investigation of metallurgical defects, or, in addition, undertakes comprehensive research, the necessity of its existence is unquestionable.

Broadly speaking, founding consists of the selection of a suitable alloy for the work in hand, the mixing and melting of the necessary metals or grades of metals to produce this alloy and the preparation of a suitable mould. The simplicity, if not the success of these processes, depends on the existence of a reasonable design and a properly constructed pattern and core box.

Patternmaking and Design.

In regard to design, suffice it to say, that only when engineering education embraces both foundry work and mechanics may we expect to substitute constructive criticism for the futile recriminations now so often experienced.

Patternmaking is a fine art, but every foundry, at one time or another, has to contend with contraptions in wood which not only

Glasgow, January 17th; Edinburgh, March 12th, 1935.

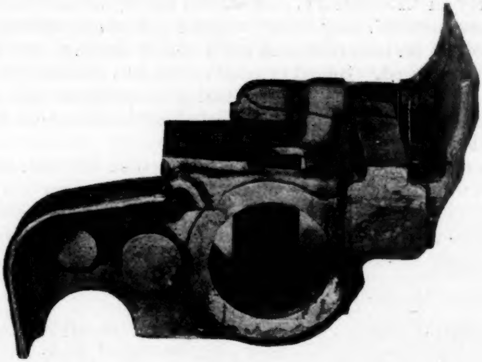


Fig. 1

Illustration of very bad design from the foundry point of view. It is most difficult to ensure machinability and soundness with such widely varying sections adjacent to one another.

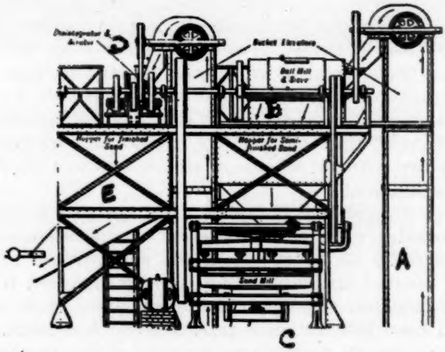


Fig. 2

One design of a composite sand preparing plant. The used sand is elevated at *A*, lightly crushed and screened at *B*, scientifically milled with a percentage of new sand in the mill *C*, and disintegrated at *D* before delivering, through the hopper *E*, to the moulding stations.

try the patience of the moulder but are a definite waste of time and money in the foundry. It should hardly be necessary to state that, other factors being equal, a good pattern is necessary for the production of an accurate and good shape casting, but this fact is not always realised. Speed of production and economy in moulding practice are largely dependant upon good patterns and coreboxes, and no ultimate savings can be effected by making this work cheap and shoddy.

Another point is that without co-operation between the pattern shop and foundry, methods of pattern construction may be good but not the most satisfactory, and where firms employ outside patternmakers and foundries the importance of these points cannot be too highly stressed.

Production Methods.

Production methods vary in almost every foundry, but, speaking generally, this variety is justified and is dictated by local conditions, the layout of buildings, class and extent of work, etc. To produce one ton of castings of small or medium size, from 10 to 20 tons of material must be handled in the foundry. This takes no account of the effort of ramming the moulds and cores so that where manual labour only is available, the speed and cost of production are necessarily slow and expensive.

The automobile and allied firms provide a demand for quantity production which enables those foundries dealing with this class of work to provide and justify means for eliminating this waste through purely manual effort and the specialised machine becomes a necessity. The majority of foundries, however, are engaged on smaller quantities, even if within the repetition class.

The ingenuity displayed by some of these people is often unique and it is in such foundries, where the most suitable tackle is not always available, that methods of moulding, coremaking, gating or gauging are evolved which in the absence of secrecy, become general developments.

The trend towards mechanisation has been somewhat slow, but a full knowledge of how to correlate the numerous phases of a foundry, in order to benefit from the substitution of mechanical means for manual handling, could not be deduced from a study of other industries. To appreciate this point it is necessary to understand how difficult some processes (such as sand mixing and core drying) are to perform in an automatic mechanical cycle, when even a small variety of work is being handled.

The obvious development from this consideration was that essential materials, like sand, should be studied more closely and, in its preparation, scientific means supersede the almost universal heavy roller mill, which did as much harm as good. The old method of

judging the temper of a sand mixture by feel is quite satisfactory when skilled moulders are employed, but in continuous casting systems, better means of control are essential, due to the generally larger volume of sand which must be prepared and its subsequent use by semi-skilled labour. This control consists of accurately measuring all constituents and a correct method of mixing, followed, if necessary, by a comprehensive series of tests for the required properties, namely, porosity, moisture content, and dried and undried strengths.

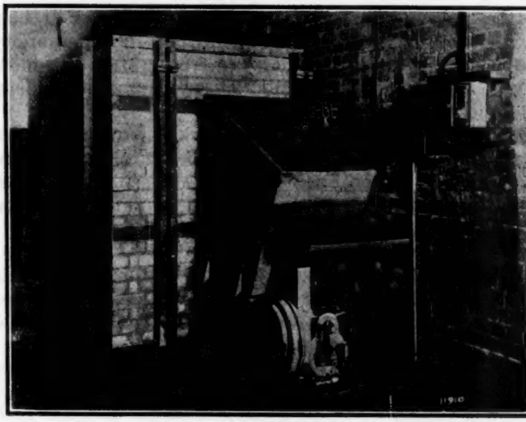


Fig. 3

A recent design of stoker for firing mould and core drying stoves. The fuel used is coal of small nut size. Three feeds are provided through a gear box and clutch seen underneath the hopper. Air for combustion is provided by a fan fitted with a damper on the intake and enters the burning zone through a series of tuyeres in the combustion chamber. The coal is propelled by a screw through a tube to the seat of the fire and because the coal is pushed up to the fire and not fed on top in the ordinary way, temporary "blacking out" is eliminated, and consequently a more uniform temperature curve is obtained. Electric control is made through a thermostat in the stove, or a time switch, according to whether the stove is in use or just to keep the fire in whilst the stove is empty. Its greatest advantage is its automatic operation and economy, as coal is much cheaper than coke.

For coremaking, sand of very high silica content which contains little or no natural clay bond is almost universally used, bonded with an oil compound which confers great dried strength, high permeability or porosity and ease of manipulation. This sand requires a distinct mixing action, namely a rubbing, to distribute evenly the binder.

Synthetic sands, prepared by coating high silica, sea shore and pit sands with a refractory clay that has been pulverised to a very

fine state, are being extensively tried out but appear to have a rather limited application. Natural clay bonded sands of suitable grade and composition occur in very large deposits in this country and, besides being cheaper, are quite as satisfactory if properly prepared.

The types of mould and coremaking machines are so numerous and each has found a place in so many efficient plants that to particularise would be both invidious and impossible within the scope of this paper. Typical installations will be illustrated which will cover the field as far as possible.

Overhead distribution of the prepared sand to the moulding stations, and mould transfer by some form of conveyer to the pouring station, are the major handling operations in the foundry. The return of the sand to the mixing apparatus after the moulds are knocked out and mechanical furnace charging and metal distribution complete the main cycle.

Coremaking is usually carried out in a separate department to which sand must be supplied. Band or pendulum conveyors transport the cores to either fixed or continuous drying stoves, after which, a graphite coating is sprayed on and gauging takes place before the cores are distributed to the moulders.

Coal or coke fires, fitted with forced draught to provide proper circulation of hot air, have been found to be more efficient than gas, oil or electric heating units for mould drying stoves, and when fitted with a thermostat, the temperature can be controlled within plus or minus 2°F. Melting plants are undergoing considerable change both in regard to their metallurgical efficiency and their operating cost.

The cupola is still the most general furnace for iron, and whilst many up-to-date firms use the orthodox design which has been in use for many years, the British Cast Iron Research Association has developed a type known as the balanced blast cupola, which aims at fuel economy by controlling, more accurately, the air entering the furnace for combustion.

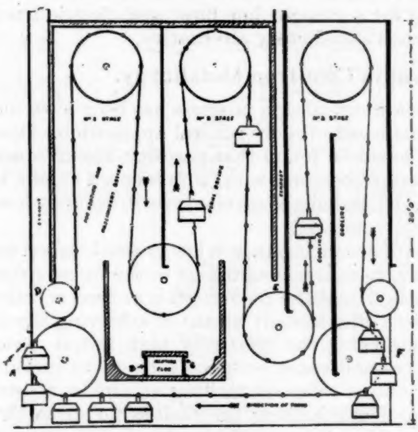
In America, one type of cupola uses air preheated to about 600°C. and is producing molten iron from the tapping spout at 1475°C., which is about 75-100°C. higher than from the average cupola in this country. Substantial fuel economy is claimed, and a further very interesting development is that this type of cupola is now working continuously, in conjunction with a pulverised coal fired air furnace, for further refining of the iron. The installation is working on chilled car wheels, and iron is melted and refined with a fuel consumption equivalent to only 195 lbs. of coke per ton of iron and is tapped at a temperature of 1560°C.

Superheating of cast iron promotes greater solubility of the carbon in the iron, and by reducing, in this way, the graphite nuclei present, enables a finer state of graphitisation to be precipitated during the

solidification of the casting and thereby a stronger and closer texture. This fact accounts for the development in pulverised coal-fired rotary and reverberatory furnaces, the electric furnace having proved too costly to operate in this country, except in special circumstances.

Fettling.

Finally, the cleaning of castings must be dealt with so that no congestion takes place. The fettling shop is often one of the most



ACME PATENT THREE STAGE CONTINUOUS CORE STOVE

Fig. 4

Section of continuous core drying oven. Trays suspended between chains travel round a series of sprocket wheels and carry the cores for a definite period of time through the heating chamber to effect the drying. Afterwards they pass through a cooling chamber so that at the discharge end they are cool enough to handle. The great advantage is a definite time cycle and economy in floor space. The heating may be done by any convenient medium, but must include a forced hot draught.

dusty departments in a works. In an effort to eliminate this condition, which is not only unpleasant but very unhealthy, as the men are likely to contract silicosis, a high pressure water cleaning system has been evolved which not only eliminates dust but facilitates greater production.

The castings, containing cores, and, with sand adhering on the outside, are placed upon a revolving table inside a room, from the outside of which a number of water jets are manipulated. The sand and water after cleaning pass to a series of settling tanks from which the water may be withdrawn for re-use. The space occupied by this

plant is fairly considerable and this point is the only serious objection to its adoption, although savings up to 90% in cleaning time are claimed, excluding chipping and grinding. There is no such plant in existence in this country at present, although several are contemplated.

Grinding machines and wheels, which give a surface speed of 9000 feet per minute, have been developed, whilst portable pneumatic grinders and chipping hammers are standard tools in most foundries. Roller conveyor is the usual assistance to the transport of castings through this department, but in the older foundries the difficulty is in arranging for a straight line flow, and electric trucks and trestle boxes provide a satisfactory alternative.

Development in Cast Iron Metallurgy.

On the metallurgical side progress has been even more rapid, and the results achieved of more general application. Dealing with cast iron first, it has been found that porosity, the greatest trouble most foundries have to contend with, is influenced chiefly by carbon and phosphorus. By keeping these elements reasonably low, porosity can be substantially reduced.

The means of producing an iron low in total carbon and phosphorus are quite numerous. Steel additions to the furnace melt is the most common method, and the pulverised coal-fired reverberatory or the rotary furnaces offer a ready means of achieving the desired result; the objections being the relatively high initial cost, fairly heavy upkeep charges and space occupied for a given melting capacity.

A recent process relies on melting an almost all-steel mixture in the cupola and graphitising the molten metal so that it becomes machinable with calcium silicide, ferro-silicon or other suitable substance. These processes need very exact melting procedure under the direct supervision of a qualified technical man, but the results are almost unobtainable by other means.

Tensile strengths up to 45 tons per square inch have been obtained, whilst strengths of 30 tons per square inch with high resistance to wear and heat are commercially possible, and with suitable heat treatment, either before or after machining, very high Brinell figures, in the neighbourhood of 700, can be obtained. Incidently, crankshafts and camshafts for automobile engines have proved successful in this material.

Additions of nickel and chromium to cast iron are now almost everyday practice in many foundries with molybdenum and copper to a lesser extent. The general effect of nickel in small quantities is to graphitise the carbon in the iron and thereby produce a softer and more readily machinable material. The type of graphite precipitated is finer than that obtained from the action of silicon, so that, in suitable sections, it may improve the wearing qualities

of the cast iron. Its general use is restricted, however, by its high cost.

Chromium, on the other hand, combines with the carbon to form hard carbides and therefore produces a harder and somewhat stronger iron. Used in suitable proportions, it improves resistance to wear and is suitable for gears, cams, brake drums, etc. It also resists the corrosive effect of acids and oxidation at high temperatures. Its effect is made more uniform when used in conjunction with from two or three times its weight of nickel.

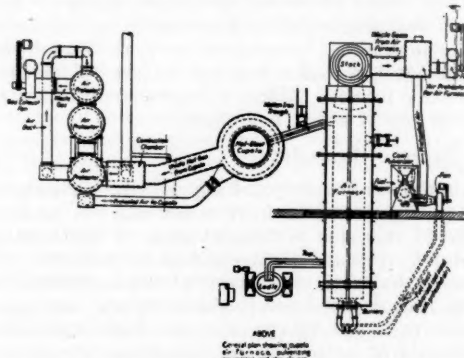


Fig. 5

Plan of hot-blast cupola working in conjunction with a pulverised coal-fired air furnace. The blast preheating stoves on the left are heated by taking hot gases from above the charging door of the cupola and passing them through tubes. Around these tubes the air for combustion in the cupola is blown and becomes heated to 600°C. The molten iron from the cupola is run into the air furnace for a refining process. It will be noted that the air for combustion with the pulverised coal is preheated from the stack.

Molybdenum is added up to .8 per cent. to aid the refinement of the grain structure and increase the tensile strength, whilst copper acts somewhat similarly to nickel, and is used to replace this element in part in the production of some austonitic cast irons. In this latter type of material a structure is aimed at which, after quenching in cold water from 950°C. has a very high tensile strength and a slight degree of ductility. It resists corrosion extremely well at elevated temperatures, as well as being practically non-magnetic.

The question of alloy cast irons is certainly one concerning the future of the cast iron industry, but it is as well for engineers to appreciate that the subject is rather in its infancy and they should not stipulate specifications which may only be capable of fulfilment experimentally.

Apart from the use of limestone in the cupola, fluxes have not been greatly used except soda ash. This material, which is dehydrated washing soda, is extensively used for sulphur reducing. Approximately 25 to 50 per cent. reduction is possible according to the amount of sulphur present and a considerable cleansing and grain refinement is effected.

The soda ash, in granular form, is added to the ladle, together with finely powdered limestone in the proportions 4 soda ash to 3 limestone. A less effective method is to add the soda ash in the form of fused blocks to the cupola charge. Another flux utilises powdered aluminium as one constituent to create heat to overcome the normal fall in temperature in the iron during fluxing, and then an effective oxide remover to get rid of the insoluble aluminium oxide formed. When a large amount of scrap cast iron is melted, the use of a flux is desirable.

The Non-Ferrous Foundry.

In the non-ferrous foundry, melting procedure has also undergone revolutionary changes which have contributed in no small way to the advance of this side of foundrywork. Contamination of the molten metal by furnace gases resulted in pinholes and oxidised segregations in the castings. This is almost inevitable in furnaces like coke pit fires or some reverberatory types, although, in many circumstances, these are still the most economical furnaces available, and with the aid of suitable fluxes, oxidation is reduced to some extent.

Gas and oil fired furnaces provide greater combustion efficiency, and their design enables the molten metal to be protected from the furnace gases to a much greater degree. However, the refractory crucibles in which the metal is melted are not impervious to gases and precautions are required in their operation, if the highest results are to be obtained.

The electric high frequency induction furnace is, metallurgically, the ideal melting unit. The electrical equipment necessary, however, is very expensive and this high initial outlay accounts for the relatively small number of these plants in operation.

The importance of proper melting, if complete homogeneity of the metal is to be obtained, is now fully appreciated and many low physical test results, particularly in aluminium alloys, which have, in the past, been looked upon as almost inevitable, have been proved to be due to overheating, oxidation of one or more constituents, or some other factor in bad melting practice.

Centrifugal casting of phosphor bronze gear wheels is now carried out on scientific lines which enables the maximum physical properties of an alloy to be developed. When centrifugal casting is impracticable, the use of suitable denseners on the face to be gearcut

produces a grain structure and homogeneity unobtainable in a sand moulded casting.

Why the accuracy and finish of die castings cannot be produced in iron and bronze castings made in sand moulds, seems to appear inexplicable to most engineers. Finding a suitable material to withstand the heat of the molten metal is, of course, the controlling factor and one which, so far, has proved economically unobtainable. Small brass and aluminium bronze castings are possible, but the life of the dies is short and the process therefore becomes expensive, if the design is at all intricate. Zinc base and aluminium alloys are handled by both the gravity and pressure feed systems with excellent results.

Finer limits of accuracy are possible in the pressure die casting, but greater skill is required in designing the die. Determining the size and location of the runner or inlet for the molten metal and the vents or passages through which the air is expelled as the metal fills the mould, is work for experts. Modifications of design may be essential or desirable to facilitate production, and here it may be mentioned that if the greatest measure of success is to be achieved in diecasting, the designer must co-operate with the foundry.

Since the introduction of the aluminium alloy known as "Y" alloy, and the effects of the phenomenon of "age hardening" were discovered, alloys of aluminium with nickel, copper, magnesium, silicon, and manganese have been greatly developed. Most of the alloys require heat treatment after casting to develop the physical properties, but because of their high liquid shrinkage, every casting becomes a problem unto itself in order to ensure absolute soundness.

The application of these alloys has been more or less confined to automobile and aircraft work, but their greater usefulness for general engineering is worth investigating.

The difficulties which beset the aluminium founder are many, both metallurgically and in shop practice. To fulfil the rigid specifications often required, it is necessary to use only virgin metals, and the cost, therefore, is relatively high.

The question of the use of secondary metals, which are scrap of possibly various analyses refined to within narrow limits of standard specifications, is one which is often looked upon with doubt, not only by the engineer but also by the metallurgist. However, the percentage of impurities present need be very small and of such a character, that not more than five per cent. reduction in the physical properties will occur. It is only by the use of such alloys that the price of commercial castings, for which no particularly special characteristics are necessary, can be profitably produced.

Conclusion.

In conclusion, there are one or two factors I would commend to your notice. Efforts are continually being made by foundries to

meet the constantly increasing demands made by the engineer both in regard to quality and price. Defective material, apart from its reflection on the foundry, is, of course, the cause of delays and congestion, as well as expense, to the production manager. However, it is necessary to point out that the foundryman is at the mercy of the supplier of his raw materials, and although he may have absolute check on the receipt of these, pig iron, for instance, can only be brought within certain limits and the variable quantities which will always exist will preclude the guarantee of 100 per cent. good castings for some time to come.

Competition demands that the price of an article shall be the lowest possible, compatible with quality and a reasonable profit. Many factors enter into this question, and in the case of castings if it is admitted that productive methods are the responsibility of the foundry, it must be realised that, to reiterate what has already been said, designs must be reasonable. Although there is little that is impossible, the greatest efficiency is bred from the simplification of mechanisms and processes.

I gratefully acknowledge the assistance I have had in illustrating this paper by the loan of lantern slides or samples from :—Messrs. Foundry Plant & Machinery, Ltd., August Muffle Furnaces, Ltd., Foundry & Engineering Co. Ltd. Imperial Chemical Industries, Ltd., Mr. Molyneux, Messrs. Morgan Crucible Co. Ltd., Foundry Services, Ltd., Fordath Engineering Co. Ltd., Foundry Equipment, Ltd., Herbert Morris, Ltd., Bagshawe & Co., Ltd., "Iron Age" Journal, and Alfred Herbert, Ltd., with whose permission and assistance I have been able to give this paper.

Discussion, Glasgow Section.

Mr. Mallett: One thing interested me was the use of moulds without boxes. It is a new practice on large work as far as I am concerned. What weight can be cast by that method? Do you tie the top to the bottom by means of a dowel or some form of print? You mention where the core was costing 20 per cent. more than hitherto, but that the ultimate casting was 15 per cent. lighter. It struck me that this would show a definite saving in the ultimate job. I should think it would more than pay for the extra cost of the core apart from achieving the designer's object of getting a stronger bed.

"Denseners"? I think you used this word purposely instead of "chills." When does a densener become a chill? When does a casting become easier to machine? Can you control the hardness in such a way that you can get your object in reducing porosity without giving trouble in the machine shop? Or do you meet it by saying "you have got to grind that part because we must have a heavy enough chill in order to avoid porosity? Does flux help you in itself to reduce hardness? You must put chills in with a small portion of sand—it struck me that $^3/_{16}$ in. was a precarious thickness. Could you not overlap the chills rather than have a bridge of sand between?

You show the rotating table method of sandblasting. Do you show that because of your preference for the method? What do you think is the best method of sandblasting castings? Is the sandblast rumbler a real help and an efficient machine? Our own experience is that it is one which requires a lot of expensive maintenance.

Mr. Morgan: The question of the snap-flask method of moulding which is the boxless mould—this is applied to small work, and the box which is used to make the mould is hinged at one corner and at the opposite diagonal corner there is a catch which enables you to open it. The mould is made, removed from the pattern, placed on a board, and put down on the bed ready for casting. Any cores are put in and the runner is cut. Then the top half of the mould is made and located in relation to the bottom half by the ordinary pin and lug. The heaviest casting I have seen made weighed about nine or ten lbs. It is a very quick method for small work but it is rather difficult to advise. The only thing is for you to see a foundry who utilise that method.

The cost of bed parts compared with the ultimate cost of the casting. I quite agree that the ultimate cost of the machined casting may be less but "every man for himself." The weight of denseners which will preclude the possibility of hard castings. If you want

a densener to overcome porosity it must be adjusted so that approximately its own thickness is equal to the thickness of metal section it is desired to cool more quickly.

Now, on the beds or milling machine columns we put chills on the slide faces, to close the grain of the iron. These must be kept at least ¼" from edges. The question of a 3/16" gap between adjacent denseners, on a surface which is too long to be covered by one densener, is not really fine. The sand in this case is in compression when the denseners expand on being heated as the mould is poured and this will cause the sand to be squeezed up which will cut down the machining. Where two denseners run closely together it is necessary to cut out or press back the sand between, so that when the denseners expand the sand will be pushed up no further than the surface of the mould.

Hardness when denseners are used is really a question of adjusting the composition of the iron. I mentioned that by using denseners we are enabled to use a softer iron to preclude the possibility of hard spots in the thinner sections, yet obtain a dense hard wearing surface on the chilled face. Take a lathe bed : the top face may be 1½" to 2" thick and the ribs on the bottom only ½". If you were to cast the bed part with the correct composition it would give you an unmachinable part on the ribs. By chilling the heaviest sections a softer iron can be used which makes it possible to machine the thinner sections.

To densen a machined face you may take it that the denseners must be three quarters of the thickness of the metal they lie against. To give you an example, in, say, a No. 20 combination lathe, we make the silicon about 1.2 per cent. If we were not to use denseners, to get a close grain on the sliding faces, we should have to drop the silicon content to 0.9 per cent. That would mean the under-ribs would be white and you would get excessive shrinkage and cause ultimate distortion.

The various machines for shot-blasting are all useful in their various ways. The rotary table machine is used for certain definite classes of work, particularly thin work such as thin plates. The chances of being mishandled are little. For heavier work the shot blast room is to be preferred, and where the demand justifies the design I would suggest a room with a roller conveyor travelling through it and men operating nozzles outside or by means of an overhead track suspend the casting inside the room and play on it from various angles. That is applied very successfully to motor-cylinder work. The shot-blasting tumbling barrel is not, in my opinion, very satisfactory except for small work. Such things as pipe fittings, taps, etc., are not successfully treated in such a barrel. If you have got relatively small castings which do not contain a lot of cores it is quite successful.

MR. McHUGH: Have you any special mixture for casting iron moulds?

MR. MORGAN: Yes. A low carbon, low phosphorous iron to resist heat and growth.

MR. McHUGH: Do you use denseners when casting the iron mould itself?

MR. MORGAN: No.

MR. BALLANTINE: Further to this block I understood Mr. Morgan to say that no coring whatever was adopted in the manufacture of these castings made in permanent moulds. Did he find that the castings were satisfactory without resorting to excessive feeding?

MR. MORGAN: In the particular casting shown, no cores are used but it is possible to use cores in holes over $1\frac{1}{2}''$ diameter on the larger sizes of castings. No feeding is done other than the natural feeding from the runner.

MR. BALLANTINE - It seems to me that porosity must be evident in the main bore.

MR. MORGAN: No. There is no porosity present at all. Another extraordinary thing is the three per cent. silicon, one per cent. phosphorous iron use; as this iron, cast in sand moulds, would exhibit a great tendency to draw in heavy sections. This iron is used however in the permanent mould casting to prevent skin hardness.

MR. BALLANTINE: It seems very strange to me.

MR. MORGAN: It is a line which we handle quite a lot, 10 tons a week. We also make a series of castings of various shapes which have to be perfectly sound and though they look simple jobs they have proved otherwise in sand moulds. This point has raised many queries but I should be pleased to show the whole process to anyone.

MR. KIRKWOOD: The mention made of pin holes in aluminium castings is interesting, because we are constantly coming up against these in alloys such as L.8, and the foundry people usually say "Well, that is very unfortunate, we might be able to do better next time." The improvement is not very great. Can I take it that the universal cause of these pin holes is overheating, or are there other factors which contribute to it?

In cleaning with high pressure water, cylinder castings were cited as an instance. Can the cores be removed from inside the water jackets by these high pressure jets, and if so, how does the water get in because its energy must be largely expended?

Does the author know of a good cold method of filling up blow holes in castings? In spite of the progress that has been made in the foundry, those of us who have to deal with castings in the machine shop realise you may have a big component which is quite all right from a strength point of view, but blow holes are unsightly. It is not always convenient to weld, and I have tried most of the cast iron cements on the market with uniform dissatisfaction. I

would like something similar to that with which a dentist fills a tooth, but cheaper.

MR. MORGAN : Pin holes in aluminium castings are very often due to bad moulding and melting practice. There are other causes which can be found in some foundries. Scrap covered with dirt and oil will cause pin holes through the oil burning to form gas during melting. Oxides and violent stirring will sometimes be apparent in the form of globules rather than patches, but usually they occur in irregular holes, and the cure is an efficient deoxidiser. There is a good flux on the market which I have found particularly useful in melting scrap aluminium. It is rather a difficult matter to talk about defects in aluminium castings without knowing the specific defects. There are so many defects and so many causes. The jet of water in the water cleaning system is $\frac{3}{8}$ in. diameter, and the pressure 1,000 lbs. per square inch. I believe it takes four seconds to bore a hole through a 1 in. board of pine, and whilst I have not seen a machine I can only say they appear to be getting through the cleaning effectively, even cylinder castings. I suppose I am rather prejudiced in regard to the last question. I say if there are any blow holes on machined faces in the casting, scrap it.

MR. KIRKWOOD : What if there is a lot of machining done before ?

MR. MORGAN : Improve the inspection before it gets so far.

MR. CRADDOCK : Can the lecturer tell us if there are fluxes used in zinc base die casting so as to give a porous free casting ? I understand sometimes a piece of coke is put in to absorb impurities.

MR. MORGAN : Absorbing impurities. I have no experience of that, but if I am not playing the publicity agent I would like to suggest there is one firm specialising in fluxes, and that is Foundry Services, Ltd., Birmingham. They have something like 30 fluxes on the market, and those which I have used are excellent, but whether they have one for fluxing zinc base alloys, I do not know.

MR. JAS. WRIGHT (Section President) : In proposing a vote of thanks to the lecturer I must say that Mr. Morgan has given one of the finest lectures we have ever heard in this room. Mr. Morgan has excelled himself both as lecturer and in the detailed accuracy of his replies to the discussion.

RECENT DEVELOPMENTS IN LIGHT ALLOY PISTONS.

Paper presented to the Institution, Coventry Section, by H. J. Mabrey.

THE performance of a piston is affected mainly by: (1) Its design; (2) the composition of the material from which it is made; (3) the care taken in assembling the piston in the cylinder; (4) exterior factors, such as very particular characteristics of the engine as a whole. For the purpose of this paper, the last two factors must be ignored, since they are largely out of the control of the general piston manufacturer.

The consideration of political economics have tended to promote the development of very efficient high speed engine units in Europe rather than in the United States of America. It is, therefore, not surprising that the serious use of light alloy pistons first occurred on this side of the Atlantic, and that long after such pistons became practically standard in England, the Americans were using cast iron pistons to a very much greater percentage of their total output.

The change in government policies and the coming of the high speed Diesel engine, have brought the engineers and metallurgists of the United States of America into the field with noticeable results. They have been quick to take advantage of the "spade work" which has been done, and characteristically, they have been quick to realise the logical trend of the work of distinguished European workers.

It seems almost a paradox to state it but, for two decades the aluminium alloy piston was hampered by one of its chief assets. In other words, the low specific gravity of the aluminium alloy, and the consequent advantage that could be obtained by its use in minimising inertia stress in high speed engines particularly, was stressed almost to the exclusion of all other advantageous attributes. Pistons were often manufactured and put into use with dangerously low limits of safety in mechanical strength. Mechanical failures of aluminium pistons were common and engine designers began, not unnaturally, to modify their attitude to the light piston question.

The light alloy enthusiasts, however, persevered, and many weird and wonderful efforts were evolved, whereby an extremely light piston could be made to conform to mechanical requirements.

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These efforts took place both in the direction of the improvements of the inherent mechanical properties of the alloys proposed for use, and in the actual structural design of the piston.

To treat with the latter, first of all, the main tendency was to reinforce a piston having very thin walls and crown by means of, sometimes, quite complicated systems of webbs and buttresses. This type of design even invaded the field of the cast iron piston and very light weight cast iron pistons were produced which gave quite reasonable service.

The serious attempt to improve the physical, or rather mechanical properties of the alloys, began almost inevitably during the war, when the call for strong serviceable light alloys became very insistent. Quite naturally, the Advisory Committee for Aeronautics in this country had a good deal to do with this.

At the time of the commencement of the investigations at such places as the Royal Aircraft Factory, the National Physical Laboratory, the universities, and similar places, the alloys in common use for aluminium pistons were those consisting of aluminium alloyed mainly with copper and sometimes with additions of small quantities of other metals, even, remarkably enough, with zinc and tin. The copper content varied between five and 15 per cent. The piston castings themselves were, as often as not, made in sand moulds, and as castings would be looked upon in general as very poor examples to-day.

The report of the Advisory Committee for Aeronautics (Light Alloy Sub-Committee) was published in 1921, and made very interesting reading, since it foreshadowed the tremendous interest in, and the development of, the "Y" alloy piston. This alloy was originally suggested by the National Physical Laboratory towards the end of 1918, after much research work. It had a very uphill fight for popularity. After the war the technique of the heat treatment of this material was investigated by Dr. Rosenhein and his collaborators, and its use not only for pistons but for many other applications became more general.

A comparison of the strength and hardness of "Y" alloy, chill cast test bars in the "as cast" and heat treated condition is given in Table I.

TABLE I.

Condition	Ultimate Stress sq. inch	Elongation Per cent.	Brinell No.
"As cast" ...	13.75 tons	1	80
Heat treated ...	21-22 tons	5-7	115

Chemical composition of "Y" alloy : 4% copper, 2% nickel, .5% magnesium ; remainder, aluminium.

" Y " alloy is now universally known and a considerable number of minor variations in the composition exist, sometimes under high sounding proprietary names.

Parallel with the development of " Y " alloy ran investigations into the possibilities of the use of the alloys of magnesium for piston purposes. In a minor way the author assisted in this investigation and for several years systematically examined binary and ternary series of alloys of magnesium. The original investigators of the magnesium alloys were considerably handicapped by the comparatively high price of magnesium metal in the years immediately after the war, and the very little knowledge any of us had regarding the foundry side of magnesium work. For, in those days, the results of casting molten magnesium alloy into green sand moulds would have almost inevitably terminated the metallurgists' interest in any mundane affairs whatsoever. Even with very carefully baked moulds and cores, the resultant castings were definitely unsound and unsatisfactory. Since those days, however, the technique of magnesium foundry work has been carefully planned out by the I.G.F. in Germany and by De Fleury, Caillon, and others in France and the Dow Chemical Corporation in America.

It seems at the moment that what future there is for a magnesium alloy piston must lie with the forged article, which quite naturally demands a very simple type of design.

To revert to the problem of design, it is very difficult to dissociate the question entirely from the material proposed for use, though a very general principle may be given, which calls for simplicity and the absence of ribs and similar mechanical aids to strength.

Some years ago, in a paper on " Piston Temperatures and Heat Flow in High Speed Petrol Engines " read before the Institution of Mechanical Engineers, Professor Gibson, of Manchester quoted that :

" The design of a piston affects its maximum temperature appreciably. The best piston examined has no ribs and a comparatively thin centre, the thickness of the crown being roughly proportional to the radius. This piston is some 20°C. cooler than one of the same weight but of a heavily ribbed design."

It is the general consensus of opinion, that of the heat developed in the combustion chamber, 80 per cent. is transferred to the cylinder block via the piston rings and lands, 10 per cent. via the skirt of the piston, and the remainder down the connecting rod. It is therefore essential that every facility is given for the heat to reach the piston rings without any interruption by any form of thermal barage. Such conditions are obtained by the type of heat referred to above by Professor Gibson.

De Fleury has claimed, and his opinion has been endorsed by the French Academic Dessiences, that, provided metal of suitable

mechanical strength is under discussion, the most advantageous material for use in making the piston is obtained when the maximum is given by the following ratio :

$$\frac{\text{Thermal Conductivity}}{\text{Density} \times \text{Co-efficient of Linear Expansion}}$$

The high co-efficient of linear expansion of the majority of aluminium alloys has been a considerable draw-back to their employment, since as a first approximation it would appear that the higher this co-efficient is, the greater the amount of clearance that must be allowed in the cold between the walls of the piston and the walls of the cylinder. Fortunately it has been discovered that the use of substantial per centage of silicon mixed with aluminium produce alloys having comparatively low co-efficient of linear expansion. Table II. shows the effect of increasing quantities of silicon in lowering the co-efficient in a sample binary series of aluminium alloys.

TABLE II.

Per cent. Silicon	Co-efficient linear exp.
13	0.0000195
18	0.0000180
25	0.0000170
35	0.0000155

For purposes of comparison it should be noted that the co-efficient for cast-iron, as used for piston manufacture, is 0.000011. Table III. is a comparison of four materials used in the manufacture of pistons, the final column being " S," that is to say, the suitability according to the De Fleury ratio already referred to.

TABLE III.

Material	Co-efficient Expansion	Thermal Cond.	Density.	" S "
Cast Iron ...	0.000011	0.16	7.22	201
3L11	0.000024	0.36	2.85	526
" Y " Alloy ...	0.000023	0.40	2.80	621
18% Si, 3% Cu, remdr. al. ...	0.000018	0.42	2.60	897

There are, however, difficulties in the way of the general use of the hypher-eutectic silicon aluminium alloys, which difficulties are purely practical ones. Such materials present foundry and machine shop problems which require specialised treatment. Such difficulties, however, have been overcome and the problem of

producing sound piston castings accurately and economically machined has been solved.

In certain quarters exception has been taken to these alloys in the "as cast" condition, owing to their comparatively low Brinell hardness. This hardness is very similar to that of "Y" alloy in the "as cast" condition. It is true that by suitable heat treatment the Brinell hardness of "Y" alloy and other similar alloys can be materially improved.

The two comments that the author has to make on this are: (1) That such improvement in physical properties brought about by heat treatment is not permanent under the working conditions of a piston; (2) that it is difficult to see what particular bearing the Brinell hardness has on the actual performance of the piston.

With regard to the first comment, the figure given below shows the results of an investigation carried out by the author on chill cast test bars of "Y" alloy in 1927.

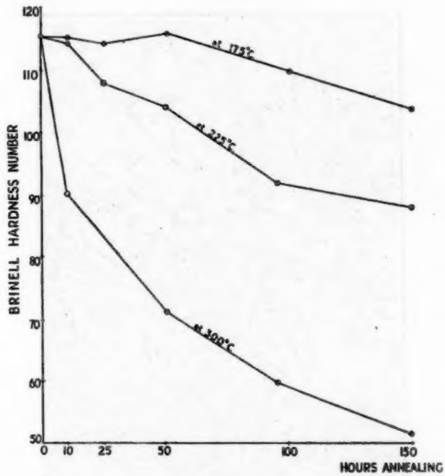

Fig. 1.

It will be seen by these curves that the effect of continuous annealing, such as is obtained in practice during the running of an engine, is very largely to dissipate the increase in hardness obtained by heat treatment. This question of the properties of heat treatment materials after long and continuous annealing, has recently received much attention in various parts of the world, and in general, the conclusions are that it is unsafe to assume that superior physical properties brought about by heat treatment, the

value of which is determined at normal running temperatures, can be taken into account when the article constructed from such material has to be used in practice at considerably higher temperatures.

With regard to the second comment as to the need for a high Brinell figure in piston material, it is a remarkable fact that a million pistons have been in use made from the eutectic aluminium silicon alloy with a Brinell hardness of under 60, and that such pistons have given excellent service. As far as the author can gather, those who have advocated the use of heat treated aluminium alloys with Brinell number of 115 upwards, have suggested that such hardness in the skirt of the piston tends materially to reduce the cylinder wear. Recent work by Ricardo has rather exploded " the cylinder wear by abrasion " bogey and has stressed the factor introduced by the corrosive effect of the breakdown products of over heated lubricating oils. In the author's opinion not enough attention has been

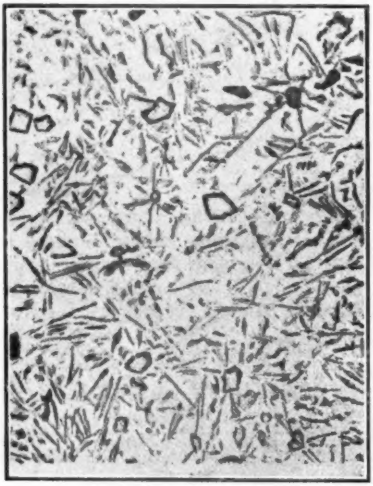

Fig. 2.

paid in the past to the microstructure of the material from which the piston is made.

The use of the various modifications of the simple binary aluminium silicon series is increasing rapidly for piston construction all over the world. It is not suggested for one moment that finality has been reached, for like every other practical problem the optimum

result is usually arrived at by means of compromise. As developments take place in our knowledge of general design in one hand, and improvements in the physical characteristics of alloys become possible on the other hand, so will vary the best compromise that can be effected.

Discussion.

Mr. Lewis: I am sure it is very interesting to hear what Mr. Mabrey has had to say about the use and development of silicon alloy. He mentioned a silicon alloy that can be hardened by heat treatment 140-150. What other elements are introduced in the alloy to bring about this hardening effect? Mr. Mabrey stressed what those of us who have had practical experience of pistons know—if you start a piston with a Brinell of 140, by continual service this figure does drop almost to the "as cast" condition. I would like to put the case that if you take an alloy "as cast" you do not subject it to any heat treatment at all; if you heat that silicon alloy and cool it, you will again get a drop in the original Brinell "as cast." If you would like to graph the drop, taking from the bar "as cast" you will find that they follow each other fairly faithfully. The higher Brinell figures will drop more rapidly than the "as cast" but if you heat them and cool them as many as a hundred times you will find there is still a difference. You do get a definite advantage from heat treatment.

When dealing with the hardness, Mr. Mabrey has stated that pistons have been run satisfactorily at Brinells of 50 and 60. I should certainly like to know something about that. Are these any particular type of pistons because it would be very interesting for certain alloys.

On this point of thermal conductivity. In a low silicon, one of, say, 18 per cent. against, say, "Y" alloy or ordinary 10 per cent. copper alloy, if the engine in which these pistons are running is not overloaded, I find that you can use a silicon piston at a closer clearance, which is an advantage. The thermal conductivity of the silicon alloy not being so good as the 10 per cent. copper alloy, you get seizures. Has Mr. Mabrey any experience with silicon alloys? My experience on air-cooled engines is that you have to give it so much clearance that the thermal conductivity with the silicon alloys is such that you don't get any advantage from the co-efficient linear expansion.

Mr. Mabrey: The element I would add to bring about the heat treatment of the 35 per cent. silicon aluminium alloy with 0.5 per cent. titanium would be a small percentage of magnesium. As a practical example of this point I once made, by request, some hardened aluminium silicon alloy pistons by adding 0.2 per cent. magnesium to our standard 18 silicon 3 copper material. These pistons were not heat treated but the Brinell number increased in the "as cast" condition to 106. The pistons were unfortunately

unmachinable in that condition and two or three thousand pistons were scrapped—a most expensive experiment!

I quite agree with Mr. Lewis in his remarks on the difference in the effect of annealing on " heat-treated " and " as cast " material. Nevertheless, as the temperature is increased the difference becomes greatly less. Alpax has a Brinell of between 50 and 60, and to my knowledge a very large quantity of pistons made in this alloy have been used in France and given satisfaction. With regard to thermal conductivity. I think you will find that the aluminium copper alloys have not so high a figure at 0.42. In the conduction of heat the design of the pistons must have an effect. If you have thermal barrages in the head of the piston you must have trouble.

MR. TIPPLE: What were the machining difficulties that arose when the alloy had magnesium in it and the Brinell was only about 110?

MR. MABREY: I don't think that you could take Brinell hardness as any indication of difficulty in the machining. Brinell is purely an indentation hardness figure; in some way it indicates the pressing hardness of the metal. Steel may have a very high Brinell hardness and be very easy to machine and you may get a bronze which has considerably more Brinell hardness and it is very difficult to machine.

We made some pistons once which were so difficult to handle that we couldn't get any of the Widia tools we use to stand up to them. After five pistons were machined the tools had to be resharpened which wasn't a very economic proposition. To-day, 3,000 pistons are now machined without the Widia tools showing wear. Several factors enter into the question, including spindle speeds, design, and other factors. Originally we had no success at all, but the difficulties have now been more or less overcome.

MR. NIXON: The particular angle from which I am interested in light alloy pistons is in any possible reaction they may have on piston rings and cylinder wear. Essentially, the aluminium pistons do not cause any more cylinder wear than cast iron pistons; that is to say, there is no effect through the aluminium picking up hard particles and lapping up the bearings. One way, however, is through the enlargement of the ring grooves in heads through the hammering of the piston rings. In some cases there have been troubles which were entirely due to this. I would like to ask if Mr. Mabrey has any evidence as to the degree in which the ring grooves hammer in the silicon alloys as compared with the other copper alloy pistons. Also I would like to ask how does Mr. Mabrey use pistons which have their top ring grooves machined in an insert of cast iron and whether he has any practical experience in that connection.

MR. MABREY: Answering the second question first, it is partly a question of machining practice and the accuracy of limits. Admit-

tedly a very very soft alloy might prove of disadvantage in such cases and I don't say we have never had a complaint, but never has that question of the enlargement of the ring grooves through hammering come to our notice, and we have put out many many thousands of these pistons.

With regard to the first point Mr. Nixon raised, personally I have never had any experience of that. There are two factors to be reckoned with in considering this. The first is the piston, the other is the cylinder block itself. If you have a very poor quality cast iron or ring you will get a certain amount of trouble. The piston manufacturer, or metallurgist, or engineer, can only deal with 50 per cent. of the problems connected with piston troubles; the other 50 per cent. are due to the manufacturer of the piston block.

Mr. Twigger : I was very interested in the machining of silicon alloys and would like to ask in what condition the pistons are when 3,000 can be machined without tool troubles. I have had considerable experience with silicon content of 11-14, and it is hardly a practical proposition to use diamond turning solely on account of the tendency in silicon alloys to porosity. We have also tried castings having, say, 15 per cent. silicon and they are practically unmachinable using Widia tools or any standard carbide tipped tool. When Mr. Mabrey refers to 18S3 silicon castings I take it he refers to "as cast." It seems that materials that have been heat treated and of high tensile properties would have more difficulty in machining, also hardness may be of value in connection with the resistance of the surface of the skirt to pick up in the cylinder bores. My observations have given me the impression that in the heat treated condition cylinder pistons cf 12 to 13 per cent. are definitely more immune from picking up troubles than other heat treated alloys.

In connection with machining the finish of gudgeon pin holes there is a tendency for the metal to roll back from the armour plates and the difficulty in approaching the size increases. Handling production quantities, diamond turning has been used, I believe, but owing to the great mortality in diamonds this had to be discontinued.

Mr. Mabrey : With regard to the condition of the casting, do you mean it is free from porosity ?

Mr. Twigger : No. Is it "as cast" or heat treated ?

Mr. Mabrey : "As cast" condition. This is where the foundry and the machine shop have to work hand in hand, and it is only by the production of castings free from pin holes that you can get this long life with your Widia tools. I have a casting here which was just taken off the shelves—it is not an exhibition sample—and it shows that we are free from pin holes in the foundry. The machine shops could not continue a week if we didn't give them

castings free from porosity. As regards heat treatment, I don't think it would affect the machining at all. I think the micro-structure is the important factor there. If your design is right, in practice you should get very little tendency to seize up. I cannot understand how you get any trouble in machining silicon alloy.

MR. WALLINGTON : Could you tell me if you have any experience in the difference in crank wear using light pistons as against cast iron ?

MR. MABREY : That is rather a difficult question, and perhaps an engineer's question rather than a metallurgist's.

MR. WALLINGTON : On the crank pin itself is there increased wear with cast iron rather than using light pistons ?

MR. MABREY : I should think you would get a less tendency in light alloy pistons than cast iron, owing to inertia stress, but I have no figures I could quote of this.

MR. LEWIS : In view of the question raised by Mr. Nixon, on this matter of Brinell heat treatment, does Mr. Mabrey recommend heat treatment to high silicon alloy, in the 20's or 30's, and does he consider the heat treatment on silicon alloy improves its condition ?

MR. MABREY : I have had no experience of heat treatment of these alloys, and as to whether I would recommend it, I would like to hedge on this. We are satisfied with our " as cast " metal at the moment. I don't think you will get any more advantage out of heat treatment, and since we haven't come up against this particular question yet I don't think I am going to worry over it ; we don't want to tackle any more problems than we have to. But I think they are merely problems because you are not used to them. There is nothing difficult now in machining 18 silicon 3 copper alloy.

MR. DENNIS : I feel I am rather pressing this heat treatment point, but I would like to know whether you have had experience of growth without heat treatment.

MR. MABREY : In " Y " alloy piston, yes. I don't think that you would apply heat treatment for the purpose of overcoming growth. That is overcome by annealing. There is one point I would rather like to mention and that is the anodic treatment of the pistons for the purpose of giving them a hard skin. I understand that the Americans are doing a considerable amount of pistons—many thousands a day—having anodic treatment for the purpose of giving them hard skin. That, I think, would overcome your difficulties regarding the hammering of piston ring grooves.

MR. COLE : I am here this evening really in the role of a learner. I am sure that we in Britain, as the pioneers of aluminium pistons, think of nothing but the product, that is, we go all out for the very best pistons we can get, but it struck me that having to rely on metallurgists a good deal, does any other factor enter into the question

—for instance, cost? (Mr. Mabrey: Yes, definitely, it does.) May I ask Mr. Mabrey is there any vital difference in the cost of these pistons, taking two similar pistons, and as I have not heard any reference to the various types of pistons, i.e., the solid piston, the split skirt piston, or the split skirt piston with the bore struck, may I ask what the general trend of design is? Can it be judged by inquiries, orders, etc.?

Mr. Mabrey: With regard to price, considerations come into it other than the cost of raw materials, but actually the cost of the raw materials is similar to that of the "Y" alloy or any other good quality piston material. The cost of the foundry work also comes into it. For the last fortnight I have been doing nothing but go into the machining costs of Diathem pistons and actually they are only 10 per cent. higher than machining "Y" alloy pistons. The cost in casting is certainly rather higher because a unit of diecasters making pistons cannot put out as many pistons in the same day made in the high silicon alloy as a gang producing "Y" alloy—the difference is something like 10 per cent. Again it is a question of if you want the best goods you must pay for them.

I purposely did not deal with the split skirt or bi-metal pistons. In fact I just touched on the subject by quoting Gibson's remarks, in saying the ideal type of piston is a "jam-pot" piston, with a crown thin in the centre, the Americans definitely recommend a piston with a Tee-slot, i.e., without the cut coming down to the end of the skirt but finishing so that it leaves a band of metal round the edge of the piston. The split skirt piston is easy to fit, and lasts the motorist well, but it is later when he finds his oil consumption going up that trouble comes with the split skirt piston.

Mr. G. Hey (Section President): I think we have had a very interesting paper and a very interesting discussion. I thank those gentlemen who have taken part in it. It has certainly given me a few things to think about; one is that we, as production engineers, have not got all the troubles. I feel sorry that we had not asked our foundry friends to join in the discussion; then we might have had the foundry point of view also. As a production egnineer and a machine tool builder, the point of wear seems to be one of the important things in connection with the piston and the cylinder bore. There are two elements. We should not think of putting a soft shaft into a soft steel bore in a machine tool; we have to get two metals which will work efficiently and with the lowest amount of friction together, and we as engineers have had this difficulty in diamond turning machines. It looks as though two elements enter into it. In handling the piston, the foundry side of cylinder cells and the microstructure has something to do with it.

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